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Design and Fabrication of Composite Shafts

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ABSTRACT

Substituting composite materials for conventional metal structures has many advantages because of higher specific strength and stiffness of composite materials. The Advantages of composite shaft in motorsports where weight is important criteria in determining the performance of vehicles. The weight reduction of shaft has certain role in overall weight reduction of vehicle and is highly desired, if it can be achieved without decrease in quality and reliability. This project work deals with design and manufacturing of composite shaft with the objective of increasing the strength and stiffness of shaft by trying out different fiber and matrix volume fraction.

KEY WORDS: Composite materials, fabrication, design.

1. INTRODUCTION

Nowadays, composite materials are used in large volume in various engineering structures including spacecraft's, airplanes, automobiles, boats, sports' equipment's, bridges and buildings. Widespread use of composite materials in industry is due to the good characteristics of its strength to density and hardness to density. The possibility of increase in these characteristics using the latest technology and various manufacturing methods has raised application range of these materials. Shafts are usually made of solid or hollow tube of steel or aluminum. The composite drive shaft has many benefits such as reduced weight and less noise and vibration. However, because of the high material cost of carbon fiber epoxy composite materials, rather cheap aluminum materials may be used partly with composite materials such as in a hybrid type of aluminum/composite drive shaft, in which the aluminum has a role to transmit the required torque.

Composite consist of two or more material phase that are combine to produce a material that has superior properties to these of its individual constituent. Technologically the most important composite are those in which the dispersed phase is in the form of fiber. The design of fiber-reinforced composite is based on the high strength and stiffness on a weight basis, the principal basis. The principle fibers in commercial use are various types of glass, carbon, graphite and Kevlar. Here carbon fibers are selected as potential material for the design of shaft.

Design of Composite Shaft: The specifications of composite shaft are same as that of steel shaft for optimal Design.

Composite Laminate Design: The building block of a composites material is the ply or lamina and matrix. Plies or lamina are stacked together (different orientations and materials can be combined) to make a laminate. The most common plies are unidirectional plies and fabric plies. If each ply in the stacking sequence or lay up making up a laminate is denoted by its orientation θ° relatives to a reference axis [-90° < θ° ≤ + 90°] then a laminate can be denoted by its stacking sequence or layup [θ1 / θ2 / θ3] n, where, n = no. of plies, θ1, θ2 etc. are the angles of successive plies starting from the top of the laminate. Types of laminates are symmetric, balanced, cross ply, angle ply.

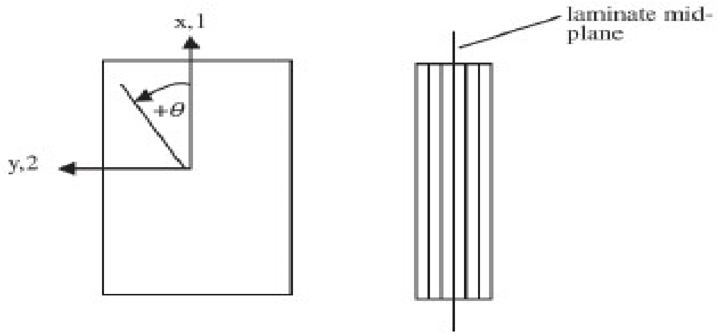

Figure.1. Laminate Fiber References

Composites laminate modeling depends on the lamina properties and ply orientation (Figure.1). So, we are estimating the lamina properties using rule of mixtures. Initially we assume the symmetric cross ply for stacking sequence. Symmetric cross ply, [0° / 90° / 90°/0°/…]n. Rule of mixtures: rule of mixtures is a method of approach to approximate estimation of lamina properties based on an assumption that a composite property is the volume weighed average of the phase properties (matrix and reinforcing phases).

According to rule of mixtures properties of composites laminate are estimated as follows: Consider a carbon – epoxy laminate consist of 70% fiber volume fraction. Use chosen carbon fabric and epoxy properties, to determine the design parameters of laminate.

2. MATERIAL PARAMETERS

Table.1. Material Parameters

Carbon fiber specification			Matrix specification		
3k bi-directionalFAW	=	200 gsm	Young's modulus	=	3.4Gpa
Axial modulus	=	230GPa	density of matrix	=	$1134 Kg/m^3$
Transverse modulus	=	230GPa			
Density of fiber	=	$1800 Kg/m^3$			

Layup Sequence: Tailor fiber arrangement to optimize resistance loads; 45 degree plies gives buckling stability and carry shear; 0 degree plies give column stability and carry tension and compression; 90 degree plies carry transverse loads and reduces Poisson ratio.

Table.2. Fiber orientation with respect to load

Configuration	Load	Orientation			Recommended layup
		0^o	45^o	90^o	
Cylinder	Torsion	0-25	50-100	0-25	[(45/-45)s]n
Cylinder	Internal. Pressure	25-33	0-25	50-67	[(90/90/0)s]n
Cylinder	External. Pressure	25-33	0-50	25-67	[0/45/-45/90)s]n
Rod	Axial	50-100	0-25	0-25	[0]n
Plate	Shear	0-25	50-100	0-25	[(45/-45)s]n

3. RESULTS AND INFERENCE

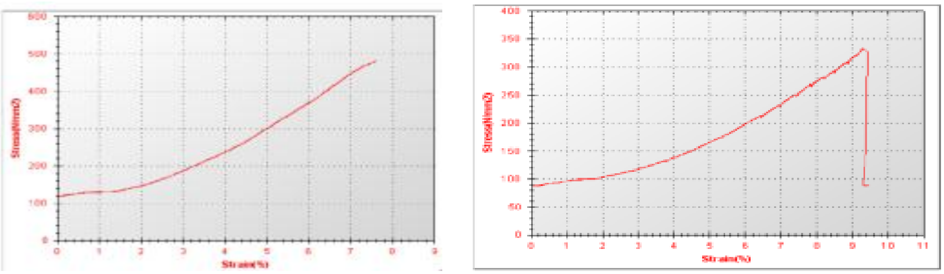

Figure.2. Mechanical Properties Identification for two different test pieces

From Figure 2 it can be inferred that test piece-1 with 0.7 fiber volume fraction gave higher yield strength and ultimate strength compared to test piece-2 with 0.6 fiber volume fraction. Therefore 0.7 fiber volume ratio (V_f= 0.7) is taken for further calculation.

Finite element analysis: Engineering layered composites involves complex definitions that include numerous layers, materials, thicknesses and orientations. The engineering challenge is to predict how well the finished product will perform under real-world working conditions. This involves considering stresses and deformations as well as a range of failure criteria. ANSYS Composite Prep Post provides all necessary functionalities for the analysis of layered composite structures. ANSYS Composite Prep Post (ACP) is an add-in to ANSYS Workbench and is integrated with the standard analysis features. The entire workflow for composite structure can be completed from design to final information production as a result. Figure 3 shows flowchart of ANSYS ACP.

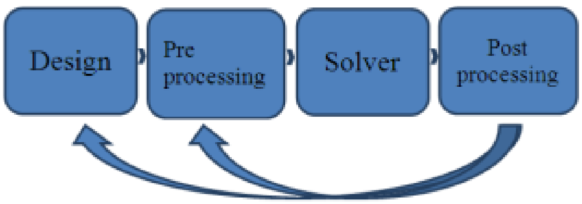

Figure.3. Flowchart of ANSYS ACP

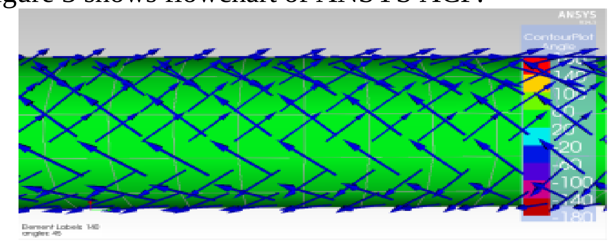

Figure.4. orientation of fiber with respect to central axis of shaft

Design of composites starts with surface cad model. Cad model was designed in Solid edge st5 and transferred to Ansys ACP. Before starting laminate design boundary conditions are defined in static structural. Then data obtained from static structural is transferred to ACP pre where laminate design is done. Laminate design starts with defining input parameters for fabric and core. The carbon fabric is 0.2mm thick and bi-directional. Then fiber orientation is specified. Since the shaft is subjected only in torsion 90% fibers are oriented in 45 degrees. The Figure. 4 shows 45 degree orientation of fiber with respect to central axis of shaft which is meant for taking torsional loads.

The stiffness of laminate will change with respect to fiber orientation, stiffness of fiber and matrix. The final laminate stiffness is obtained from Ansys and is validated using UTM maintaining same fiber orientation, no. of layers, fiber and matrix volume fraction. The stiffness along longitudinal and transverse axis are same because bi- directional fabric was used. Figure 5 shows the mechanical properties of laminate along 45 degree orientation from which engineering constants are derived. The values obtained for static structural is then transferred to ACP post where failure criteria, deformation of composite are displayed.

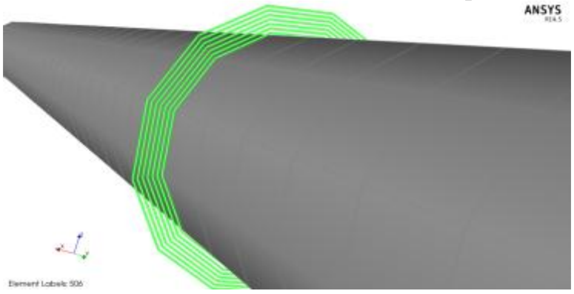

Figure.5. Mechanical properties

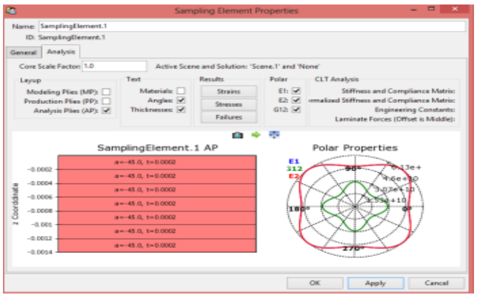

Figure.6. Mechanical properties

Table.3. Stiffness of laminate

Laminate Stiffness E1	28.43 GPa
Laminate Stiffness E2	28.43 GPa
Laminate Shear Stiffness	82.5 GPa

Table 3 shows the maximum stiffness was obtained when all the fiber are oriented along the axis of force. Fabrics aligned in different angle showed only one tenth of the stiffness when aligned along force axis. When torsion test was done on shaft the angle of twist was 8 degrees which yielded shear modulus of 82.5 GPa which can be seen from calculation.

Table 4 shows Laminate with 0.7 fiber volume fraction was found to have high stiffness and strength. Laminate with 0.6 fiber volume fraction has high matrix ratio which reduced the strength and stiffness of laminate.

Table.4. Effect of fiber volume fraction laminates strength

Fiber volume fraction	Strength
0.6	331Mpa
0.7	480Mpa

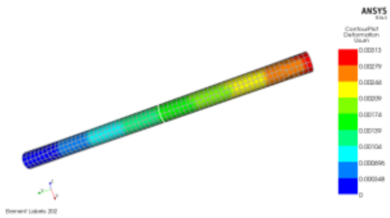

Figure.7. Deformation of shaft


Figure.8. Tested shaft

Tested shaft in Figure 8 shows breakage of shaft in 45 degree axis to normal shaft axis.

Bond length: As bond length increases the mass of insert also increases which ultimately increases the weight of component which is not desired. Therefore bond length 20 percent of original length of composite tube on either side is desired. This bond length was able to provide desired adhesion and weight is saved.

The final weight of shaft was 10 grams and if it was made with steel with same cross section it would have come around 70 grams . Therefore use of composites yielded percentage weight reduction of 85%.

Figure 9 shows the variation of thickness of composite with respect to fiber volume ratio.

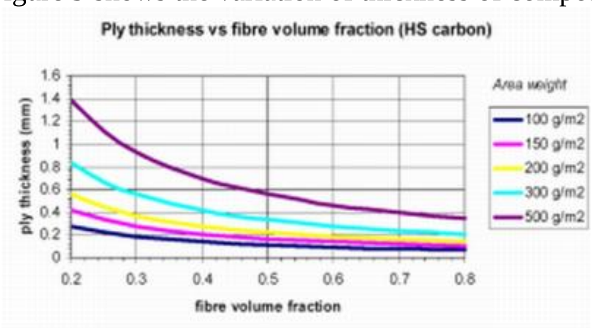

Figure.9. Ply thickness vs fiber volume fraction

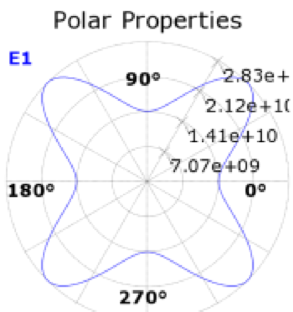

Figure.10. Polar properties

For 0.7 fiber volume ratio with fiberal area width of 200 gsm ply thickness obtained was 0.1587mm which is validated from the graph.

Figure 9 shows the orientation of fibers along 45 degree axis which is suitable stack up for torsional loads. The longitudinal modulus of laminate obtained from Ansys is equivalent to the one obtained by calculation.

4. CONCLUSIONS

The figure 11 shows comparison of different parameters like weight, strength between steel, aluminum, composite.

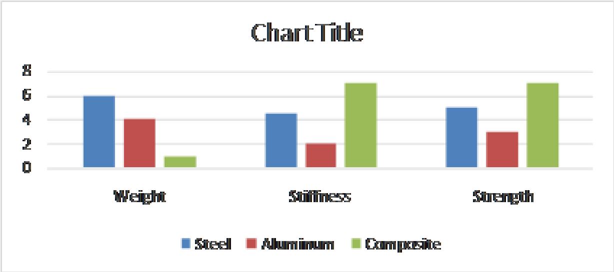

Figure.11. Comparison of steel, aluminum, composite

The specific stiffness of of composite, steel and aluminum is found to be 51.56, 10.16 and 35.6 Nmm/g. The ultimate strength is found to be 480,365,440 MPa.

- 0.7 fiber volume ratio is desired for high strength and stiffness.
- Acid etching gave better surface adhesion compared to other methods like alkali treatment, vapour degreasing.
- Use of fiberglass layer in-between carbon fiber tube and aluminum insert rectified galvanic corrosion.
- Hand layup method was adopted which will decrease the manufacturing cost of composite and is highly advantageous.
- The optimum stacking sequence for different loads was found to be

Table.5 Stacking sequence with respect to configuration and load.

Configuration	Load	Stacking sequence
Cylinder	Torsion	$[(+45/-45)_s]n$
Cylinder	Tension & compression	$[(0/90)_s]n$

Torsion test was done with fiber orientations +45,-45, 0, 90.Maximum torque was transmitted by +45-45 orientations since fibers was oriented along load axis. 0, 90 orientations yielded shear modulus of 3.5Gpa which is equivalent to shear modulus of matrix. From these tests it is concluded that max load is taken by fiber if it is oriented along load axis.

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